EXHIBIT L

REDACTED

Approximate Computing, Embedded AI, Billion Core Systems

Joseph Bates
Singular Computing LLC
Cambridge, MA

(past)
CMU CS Dept (10 years faculty)
MIT Media Lab, AI Lab

25 min

August 2017

KEY POINTS

- General purpose, programmable computers, efficiency of specialized Deep Learning hardware
- An alternative path. Retains programmer's freedom to invent. Spreads ecosystem costs over many kinds of workloads.
- Enables
  - embedded compute-intensive tasks
  - compact, practical, billion core systems

} DL and non-DL

[redacted]

UNDERLYING IDEA

Suppose machines did float arithmetic
that was wrong, but always close $< 1\%$ error

$1.0 + 1.0 = 1.98 \ldots 2.02$

What would happen to hardware and software?

ANSWERS

- Hardware
  - Arithmetic circuit shrinks 100x (standard digital logic)
    ⇒ programmable computers 25-50x better than GPUs
  - Room to improve
- Software
  - Can fix errors efficiently (when needed) in task specific ways
  - Relatively easy to program
    (serial code, algorithms studied since 80s, feels like OpenCL)
- Result
  - 10,000 core embedded chips (e.g. deploying AI)
  - Compact billion core systems (e.g. computational science)
    (cluster: of multi-million core boards)

Software

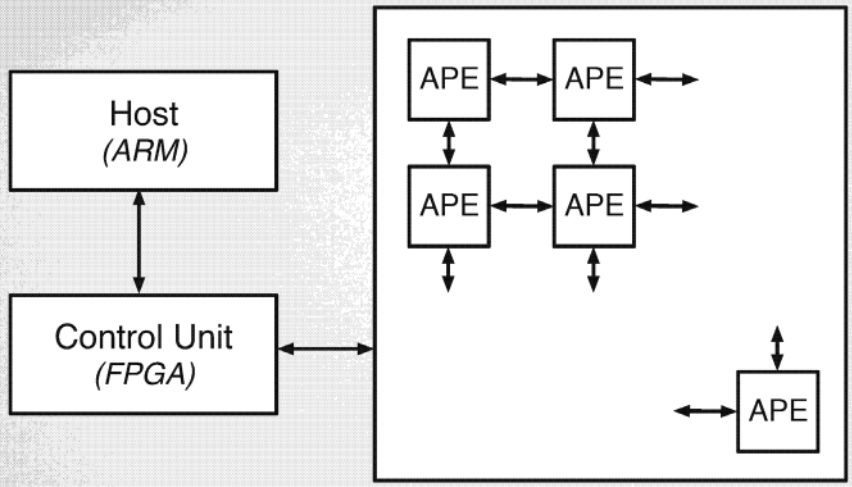
- Deep Learning
  - Berkeley (Darrell) - Inference
  - MIT CSAIL (Glass) - Training (speech, vision)
  - ImageNet CNN - Inference *demo*
  - U.S. Army - Inference (battery power handheld)
  - Speech acoustic modeling - Training
- Traditional Vision
  - Carnegie Mellon (Kanade) - Depth from stereo
  - MIT Media Lab (Roy) - Motion detection
  - U.S. Navy - Drone vision, tracking
  - Optical flow *demo*
  - Depth from stereo
  - BAE ARGUS - Gigapixel drone vision
- Optimization
  - Simulated annealing (ubqo - like DWave)
  - Genetic programming
- Others . . .

- *Study of arithmetic*
- *Running on hardware*

Purpose is Evidence:
result quality is good,
arithmetic efficiency is high,
software sufficiently easy

Hardware

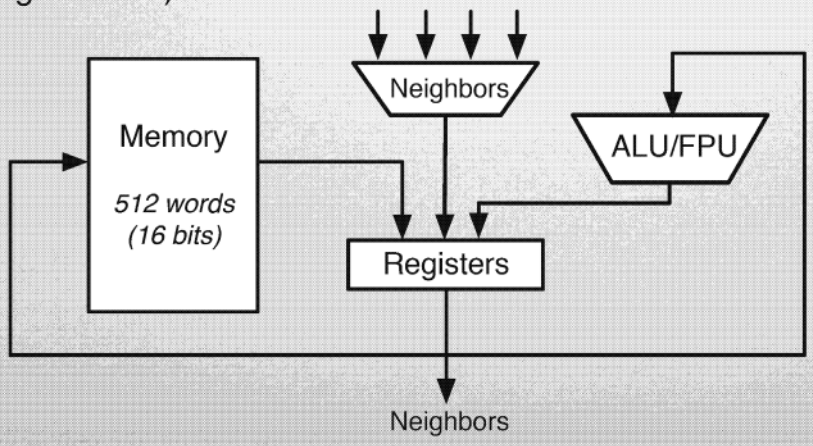
System: 2D mesh of APEs



TINY FPU NEEDS SMALLEST OVERHEAD
⇒
SIMPLEST SYSTEM

DRAM COST 500x LOCAL OP
⇒ PIM

APE (approximate processing element):



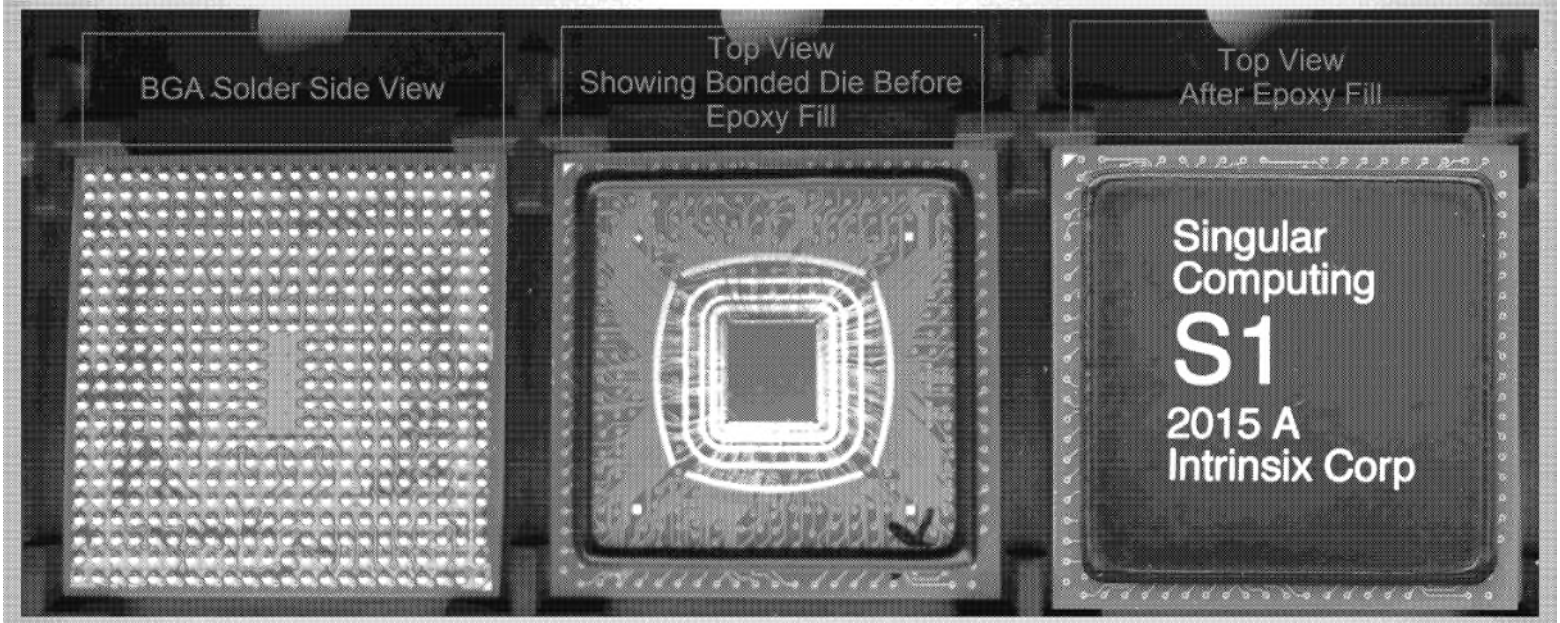
*approx float + - * / sqrt (single cycle)*

exact integer + - logical, shift

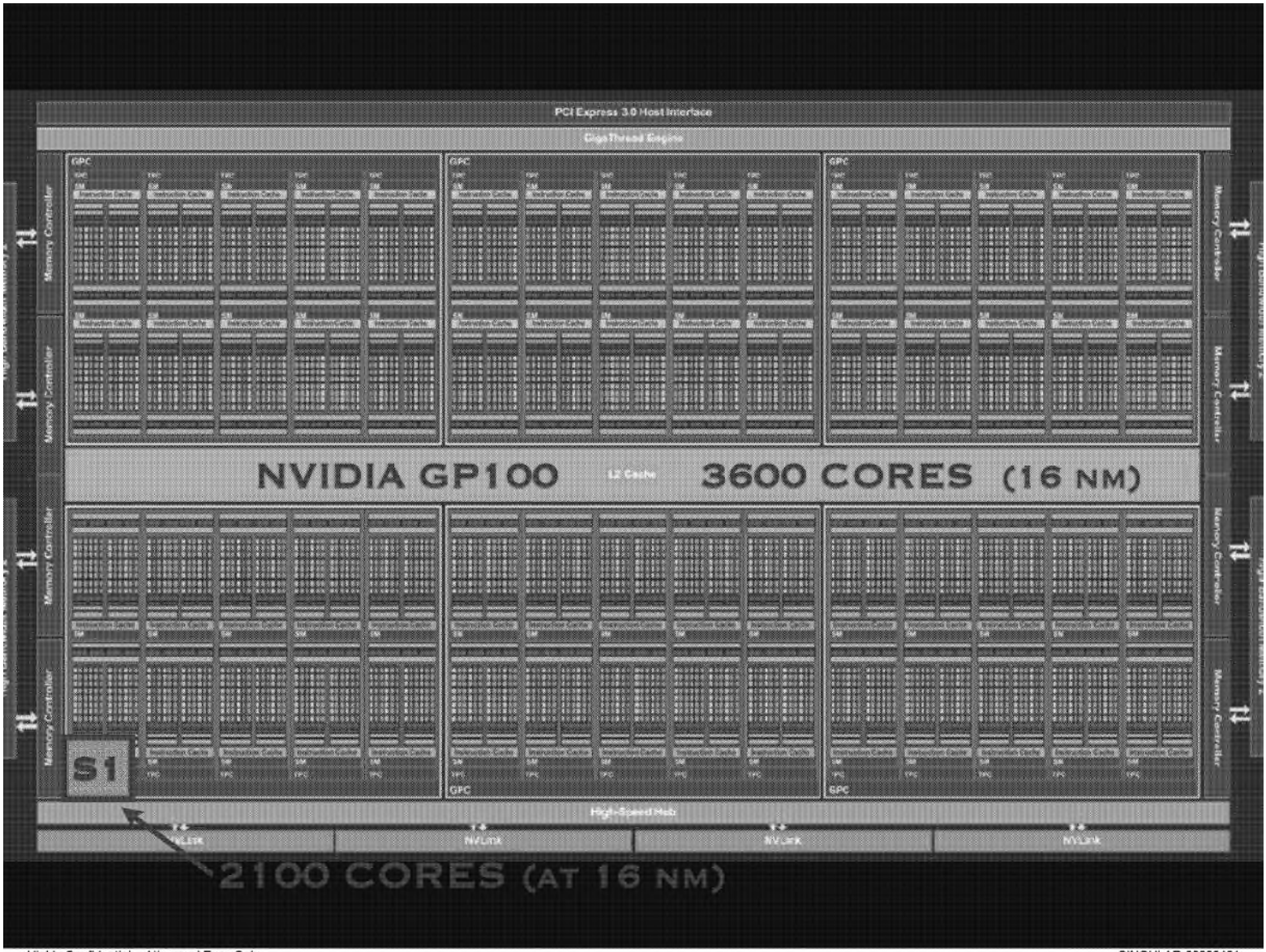
(e.g. fp32 library)

"S1" PROTOTYPE CHIP

DARPA MTO - Singular Computing, Intrinsix Corp
Cadence Design Systems, MOSIS, GlobalFoundries



2112 cores, 25 mm², 40 nm, 167 MHz, ~200 GF/W (peak)

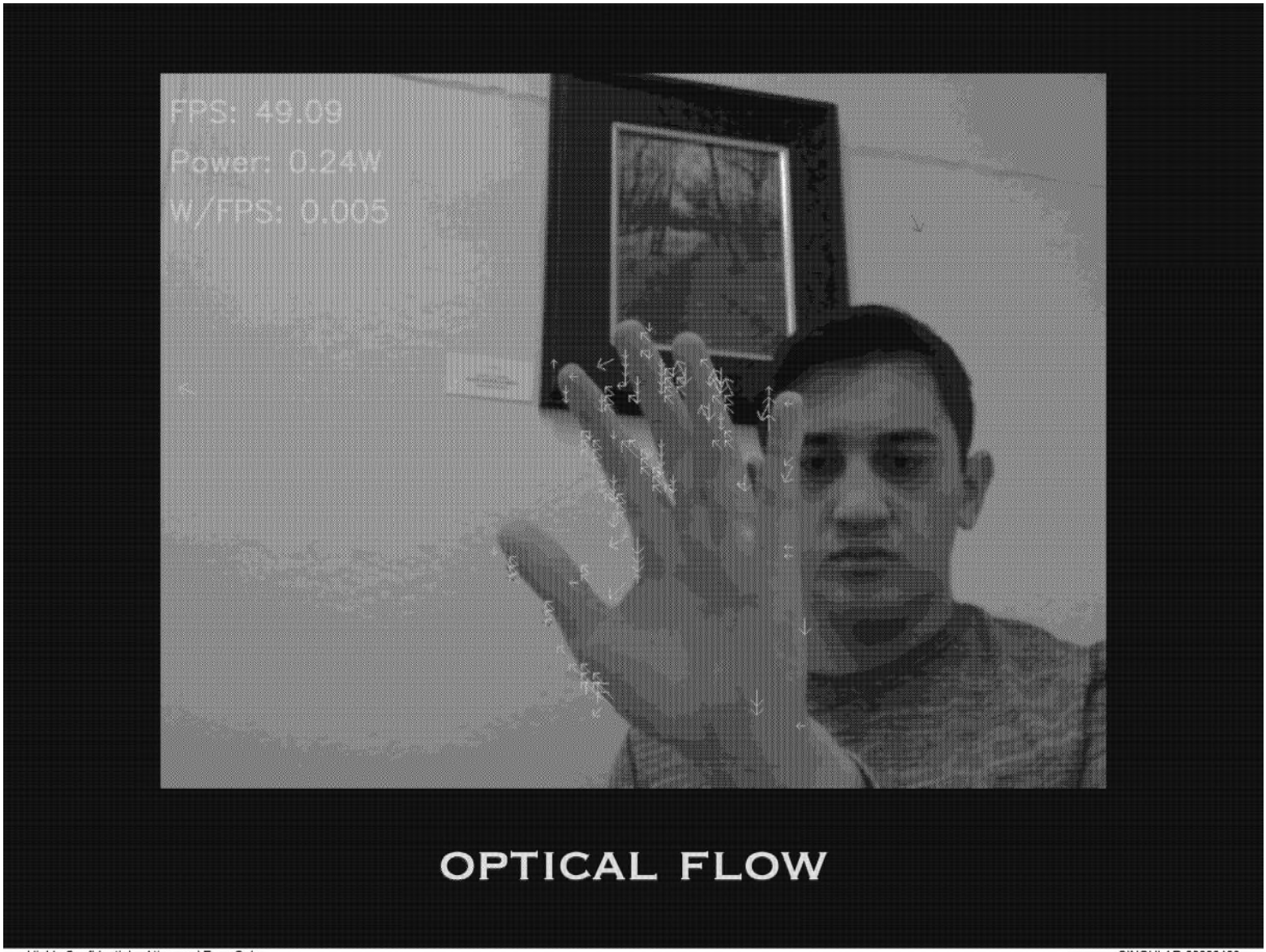

PCI Express 3.0 Host Interface
GigaThread Engine
Memory Controller
Memory Controller
Memory Controller
Memory Controller
Memory Controller
Memory Controller
NVIDIA GP100
L2 Cache
3600 CORES (16 NM)
S1
High-Speed Hub
NVLink
NVLink
NVLink
2100 CORES (AT 16 NM)

Demos

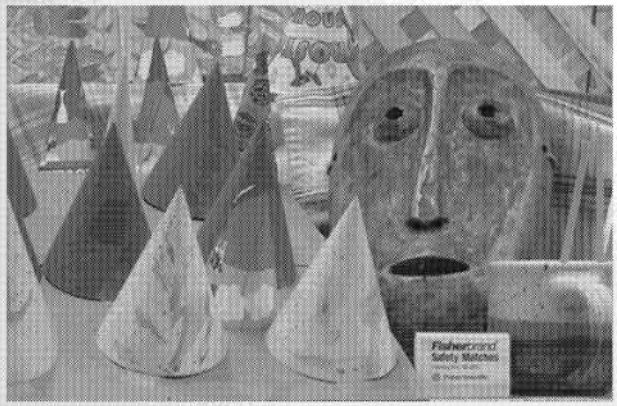
Optical Flow

Depth from Stereo

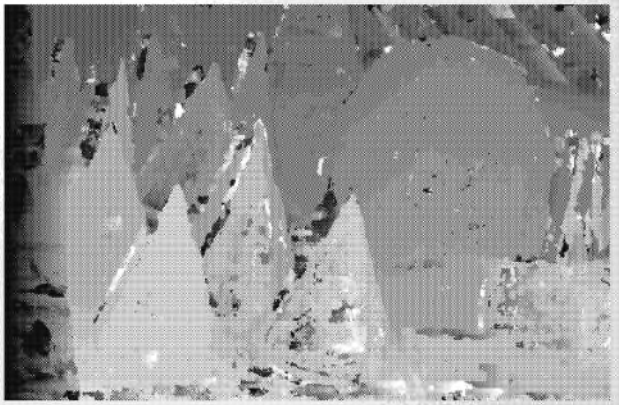
CNN Object Classification


FPS: 49.09
Power: 0.24W
W/FPS: 0.005
OPTICAL FLOW

DEPTH FROM STEREO

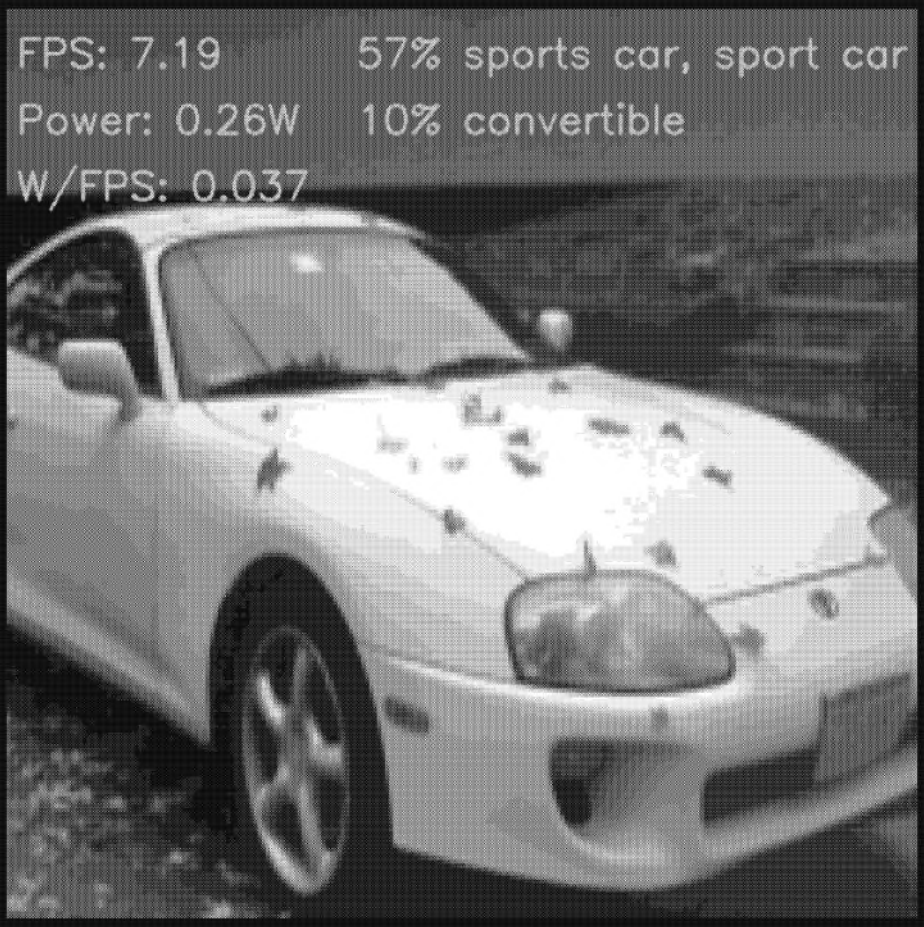


Middlebury Cones (left frame)



Depth Image

- Simplest algorithm - epipolar search
- Prototype runs 200 fps
- At 30 fps ⇒ 0.15 watts *(post-prototype ~0.01 watts)*

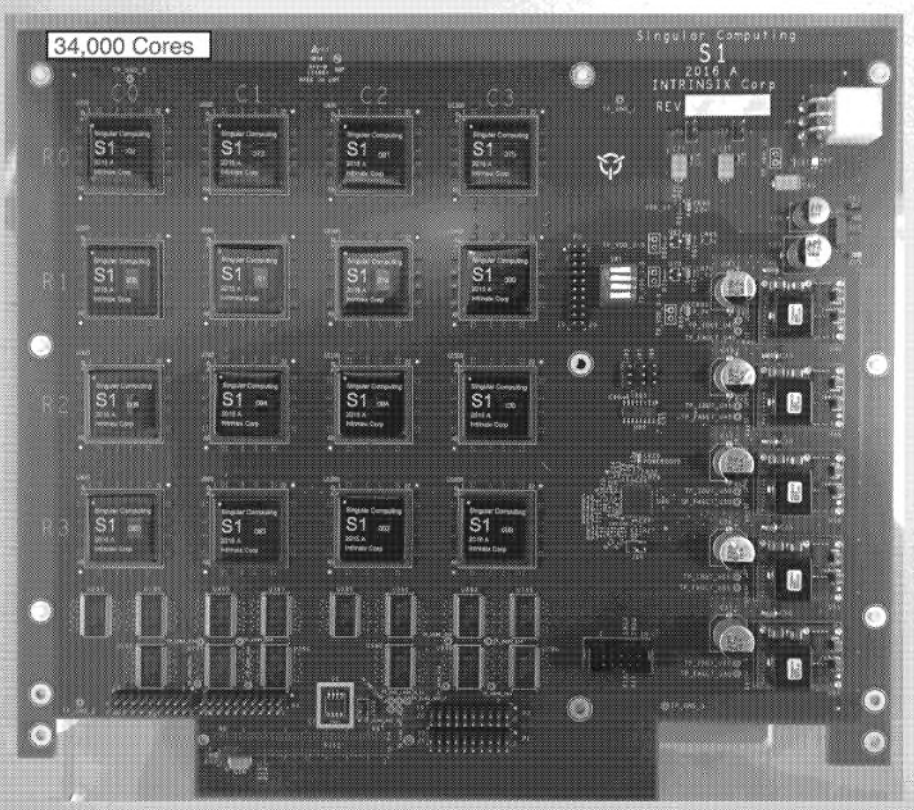


CNN CLASSIFICATION

[redacted]

[redacted]

TRYING IT OUT



- 16-chip servers on net:
  - 34K cores
  - 8.5 TFlops (peak)
  - 8.5 TB/s memory bandwidth *(10x GPU)*
- Software emulators, run on laptop
- Available now, to explore, evaluate tech

BUSINESS

- If making big investment in new computing paradigm, want generality - want good for 20 years:

  DL today ⊂ DL future ⊂ ML ⊂ AI ⊂ Computing

  [redacted]

- Approximate computing is such a technology, enables:
  - 10K core embedded computing
  - 16 million core deskside servers
  - Compact, general purpose, billion core clusters

- Weak arithmetic spec ⇒ freedom for hardware designers
  ⇒ generations of improving hardware

OUR GOALS

[redacted]

- Singular has
  - broad patents on approximate computing,
    granted in U.S., Japan, Korea, China, . . . *(e.g. US 8407273)*
  - working hardware, dev tools, algorithms, application software

[redacted]

  - 13 years experience approximate computing ⇒ guidance to partners

[redacted]